6TH QUARTERLY PROGRESS REPORT

Contract No. NSR 05-264-002

January 1968

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STUDY OF SHAPE AND INTERNAL STRUCTURE OF MOON, UTILIZING LUNAR ORBITER DATA

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LUNAR ORBITER PROGRAM OFFICE

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SUMMARY

Determinations of the lunar radius with respect to the center of mass are inconsistent with elevations shown on the ACIC lunar charts. These discrepancies may be the result of a displacement of the moon's center of volume and center of mass. This displacement may be related to a systematic excess in elevation of continents over maria. Analysis of the relationship between the moon's shape, gravity field, and internal structure requires knowledge of the coordinates of the center of figure with respect to the center of mass.

RELATIVE ELEVATION OF CONTINENTS AND MARIA

Determinations of the lunar radius by analysis of ranger impacts (Sjogren and Trask, 1965), image motion study of Lunar Orbiter photographs (Michael, 1967), and radar observations (Shapiro, et al, 1967) have yielded values which are inconsistent with the elevations shown on the ACIC charts. The origin of coordinates for the charts is a mean sphere which best fits the center of volume and the origin for the other determinations is the center of mass. Thus it has been suggested (Michael, 1967; Shapiro, et al, 1967), that the discrepancies may be the result of displacement between the moon's center of figure and center of mass. The relationship between the center of figure and center of mass must be known to accurately determine the relationship between the gravity field, shape and internal structure. Eventually it will be desirable to prepare contour maps with elevations given with respect to the moon's center of mass. With present knowledge it may be possible to approximate the moon's gross shape on the assumption of a systematic difference in elevation between continents and maria. Munk and MacDonald (1960) followed a similar approach by assuming a systematic difference in elevation between continents and ocean basins in their analysis of the relationship between the earth's shape, gravity field and internal structure.

It was previously suggested (Lamar and McGann, 1966a) that the average elevation (relative to the center of mass) of the continents is 3 km greater than the maria. Goudas (1966) questioned this assumption and pointed out that recent stereoscopic height determinations reveal no such relationship. The origin of coordinates for these systems is a mean sphere which best fits the points or the center of volume. Thus the relationship between the center of volume and center of figure must be known before any systematic difference in elevation between continents and maria can be established from the stereoscopic observations.

The problem may be visualized by imagining that the earth lacks oceans, which provide a convenient level surface centered on the earth's center of mass. An observer on the moon studying the earth's shape by stereoscopic methods or observations of the limb would logically choose the earth's center of volume as the origin of coordinates. If our lunar observer viewed the earth with the center of the Pacific basin on one limb, the center of the Pacific basin would have about the same elevation as continental areas on the earth's opposite side, relative to a coordinate system with its origin at the center of the earth's disk or center of volume. Similarly in the case of the moon it is possible that the continents are systematically higher relative to the center of mass and that some maria surfaces relative to the center of figure are higher than some continental areas. Therefore it is not possible to use the stereoscopic height determinations to establish any systematic moon-wide difference in elevation between continents and maria until such observations are transformed so that the origin of coordinates is the center of mass. Thus the authors (Lamar and McGann, 1966a,b) were incorrect in stating that Hedervari's analysis of Baldwin's (1961, 1963) data was pertinent nor does the relative accuracy of the stereoscopic determinations by different investigators discussed by Goudas (1966) have any bearing on the problem.

As shown in Fig. 1, if a systematic difference in elevation, amounting to H, exists between continents and maria on opposite hemispheres then the displacement between the center of mass and center of figure is H/2. According to O'Keefe and Cameron (1962) on the moon's earth facing hemisphere the displacement is about 1 km, the center of figure lying south of the center of mass. This is consistent with the higher percentage of continental areas in the moon's southern hemisphere and a systematic difference in elevation of about 3 km.

Analysis of tracking data from the Ranger flights to the moon (Sjogren and Trask, 1965) and the first photographs (U.S.S.R. Academy of Sciences, 1960) of the moon's farside provided the first indication that an analogous relationship exists between the moon's farside and earth-facing hemispheres. The farside pictures indicate that there is a much smaller percentage of maria on the farside relative to the hemisphere facing the earth. Thus if a systematic difference in elevation between continents and maria exists, the moon's center of figure

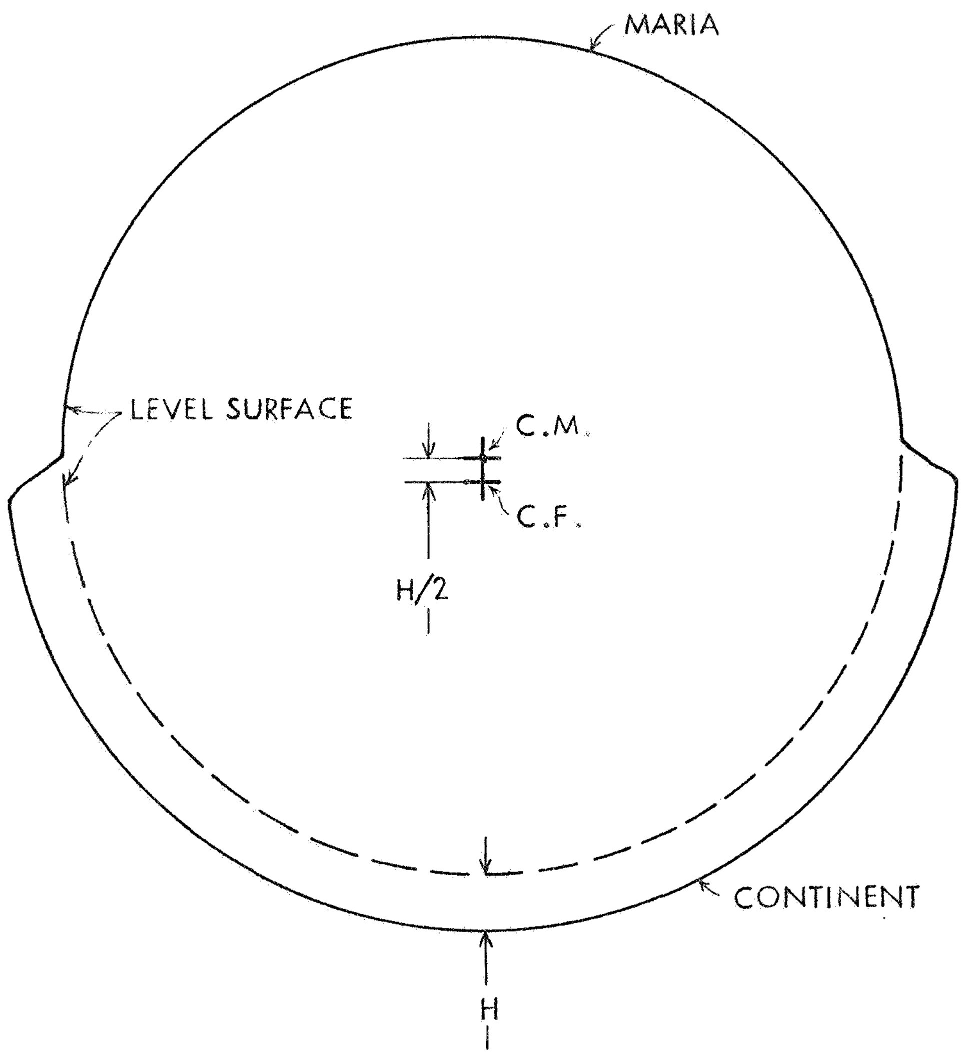

Fig. 1 Diagram indicating relationship between center of mass (c. m.) and center of figure (c. f.) for concentration of maria and continents in distinct hemispheres. A systematic excess in elevation (H) of continents over maria with respect to a level surface is assumed.

relative to the center of mass should be displaced away from the earth (Fig. 1). Tracking of the Ranger spacecraft revealed that the radius from the center of mass is about 3 km less than the value indicated on the ACIC charts (Sjogren and Trask, 1965). As the origin of coordinates for these charts is based on a mean sphere determined from stereoscopic observations, the Ranger data indicate that the center of figure is displaced away from the earth. This displacement could have been predicted from the relative absence of maria on the farside and the assumption of a systematic excess in elevation of the continents over the maria.

Preliminary determinations of the moon's radius with respect to the center of mass in the equatiroal region facing the earth have been accomplished by analysis of image motion on pictures taken by Lunar Orbiter (Michael, 1967). This investigation also reveals that the radii are systematically lower by 1 to 3 km (average about 2 km) than the radii on the curve obtained from harmonic analysis of the ACIC selenodetic control system by Bray and Goudas (1966). Measurements of the lunar radius by combining radar determinations of the distance to sub-earth points on the moon and range data of Lunar Orbiter 1 and 2 also produced values about 1 to 2 km less than the radii determined from the stereoscopic observations (Shapiro, et al, 1967).

Thus the analysis of data from the Lunar Orbiters substantiates the hypothesis of a systematic excess of elevation of continental areas over maria which is related to a displacement of the center of figure from the center of mass. However, the displacement of about 2 km between the earthward and farside hemispheres (corresponding to H/2 on Fig. 1) leads to an unexpectedly high estimate of about 5 km for the excess in elevation of continents over maria (H on Fig. 1). It should be noted that the radii determinations by image motion are concentrated in the equatorial region (Michael, 1967) which is predominantely maria; thus the relative percentage of maria on the earthward side may be overemphasized. Although additional studies of the shape of the moon are required to verify the existence and magnitude of a systematic excess in elevation of continents over maria, the existing data appear to eliminate the possibility that maria are higher than continents.

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